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PHOTOSYNTHESIS AND THE PROBLEM OF FOOD RESOURCES

By

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FTD-TT- 62-533/1+2

UNEDITED ROUGH DRAFT TRANSLATION

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English Pages: 21

SOURCE: Vestnik Akademii Nauk SSR, Nr. 11,
1961, pp. 47-58.

S/030

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FTD-TT- 62-533/1+2

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PHOTOSYNTHESIS AND THE PROBLEM OF FOOD RESOURCES

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The material base for technological progress, welfare, and the very existence of people is associated with problems of obtaining food, energy, and industrial materials. Man's energy and material requirements can be satisfied in various ways and from various sources. But nothing can replace photosynthesis of plants as a source of man's food, which he obtains either directly from the plants themselves or through animals, or even with the participation of micro-organisms. In the end, both the food supply for the population of our planet and the level of the world population depend and will depend on the volume of photosynthetic activity of plants and on the degree man uses this activity for food purposes.

The dependence of man and of all life on the earth in general, on the photosynthetic activity of plants is so cardinal that vast interest has long since been evoked by problems as to how great is its volume, what are the means and possibilities for best utilizing it, what are the prospects for increasing its scale and results, and, in connection with this, what is the possibility of providing people with a suitable supply.

Interest in these problems should increase especially now in our country, when the Communist Party of the Soviet Union has embarked on a new Program which calls for grandiose measures to master nature with all our efforts and resources since this is one of the most important conditions for the construction and existence of a communist society.

All of the world's plants annually produce up to 380 billion tons of dry biomass. This is almost 400 times greater than is needed to supply fully the present population of our planet. However, mankind annually obtains about 700 million tons of food products as based on dry biomass, i.e., less than is needed for complete satisfaction of food requirements (about 1 billion tons).

Table I shows the data on the total photosynthetic production of plants in various habitats (converted to dry plant biomass) and the degree of utilization

as food for people.* As we see from the Table, most photosynthetic products (367 billion tons out of 378 billion) are produced by the vegetation of seas, oceans, forests, meadows, and steppes. But the utilization factors of this production by man for food purposes are not very great, and in the end the overwhelming portion of the food resources (660 million tons out of 700 million) are produced by specially cultivated food and fodder plants. Therefore, the main task in solving the problem of food resources must include an all-possible increase in the photosynthetic production of cultivated food and fodder plants, which can be achieved by expanding the areas under cultivation and by increasing their yield.

By means of a possible shortening of crop rotations, reduction in the sowing of plants used in industry, and by developing new territories, the area under cultivation can be brought up to about 5 billion hectares, which will comprise about 30% of the land area (without the Antarctic and Greenland) and this must be considered as ^a very large figure, since for this purpose extensive and complex reclamation is required in a number of cases. (Some authors consider it possible to increase the area under cultivation of agricultural plants to 7 billion hectares.)

As for increasing the yield of food and fodder plants, which presently is not high on the average, we can actually count on doubling it by an efficient and unswerving utilization of presently known modern methods and farming practices (the use of fertilizers, irrigation, a careful combat against weeds and destructive insects and diseases, the selection of high-yielding plant varieties, etc.). In other words, biological yields which now have an average value of 4 t of dry biomass per hectare (see Fig. 1) can be increased to 8 t/ha on the average, which corresponds to economic yields of 30-45 centners/ha of grain, 350-400

*The Table is compiled on the basis of the data of a number of authors which do not always agree, therefore the estimate shown for the photosynthetic production of the world's vegetation should be considered as subject to some refinement.

Table 1

Plant habitat	Area	Annual prod.	Used as food	
	billion hectares	of photosynt. t/ha	total bill. tons	direct. or through animals
			mill. tons	% of total
Seas & oceans	36,1	9	325	32 0,01
Forests	4,4	3	36	7 0,02
Arable lands	2,7	11	11	660 6
Meadows, steppes	3,1	1	6	2 0,03
Deserts	4,7	0,01	0,05	—
Total	51,0		378,5	701

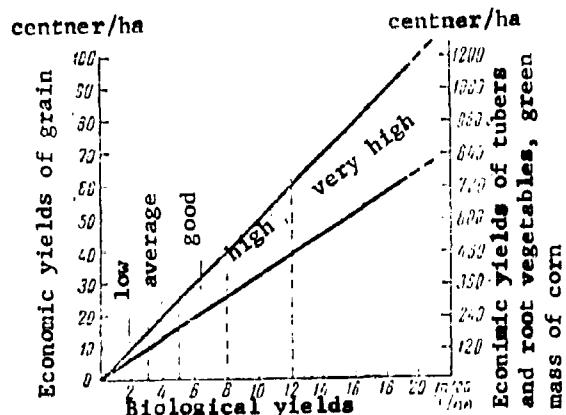


Fig. 1. Relation between biological (total dry biomass) and economic yields of various agricultural plants.

centners/ha of potatoes, 400-500 centners/ha of sugar beets, etc.* and to harvest annually, therefore, about 30-40 billion tons of total photosynthetic products from 5 billion hectares. A considerable gain can be made by improving the system for utilizing the biomass of the plants in order to obtain maximum food products, so that their yield factor is raised from the present 6% to 12-15%.

Ultimately we can expect an annual production of 4-5-6 billion tons of net food products by developing the usual methods now being used to some extent and which should be accelerated in the future. In addition, we can probably expect a two-to threefold increase in food production by using the results of the photosynthetic activity of aquatic flora.

In all, such an amount of food can provide a maximum supply to a population of about 10-12 billion people, i.e., three to four times more than the present population. But a successful achievement of this goal is not an easy task and, moreover, more efficient means than our usual methods of modern agriculture are needed for the future solution of the problem of food resources.

In connection with what has been stated, the first question to arise is whether or not we can assume that in the future, not only natural photosynthesis, but also artificial chemical synthesis or artificial photosynthesis will be the supplier of food products for man.

In our opinion, there are no grounds to think that for the mass production of the most common products, artificial photosynthesis as a food source will have any advantages over natural photosynthesis: the same solar energy is needed for it but probably complex systems of trapping it and converting it would be required, and this would have to be done on immense areas. The use of artificial synthesis and biosynthesis will apparently be advantageous only for the produc-

*See: A.A. Nichiporovich, Photosynthesis and a Theory for the Production of High Yields, "15th Timiryazev Lecture", Moscow, Izdatel'stvo AN SSSR, 1956; A.A. Nichiporovich, L.Ye. Stroganov, S.N. Chmora, M.P. Vlasov, Photosynthetic Activity of Crop Plants, Moscow, Izdatel'stvo AN SSSR, 1961.

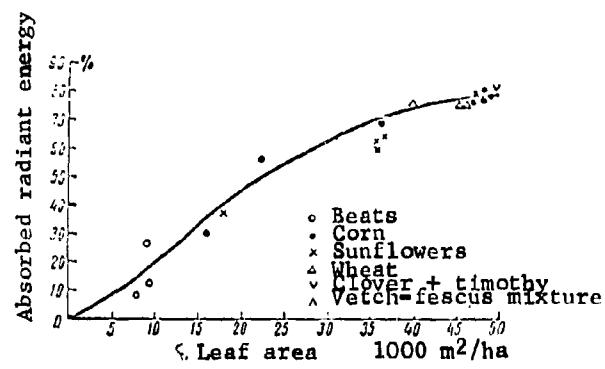


Fig. 2. Absorption of photosynthetically active radiation by agricultural crops vs. leaf area

tion of some individual food components (e.g., individual amino acids, vitamins, fats, etc.) whose required amounts are relatively small.

Therefore, the problem of food resources in the future must be solved mainly or almost wholly by natural photosynthesis of plants, and we must bear in mind that the productivity of the most promising food and fodder crop plants must be increased as much as possible.

In order to estimate the prospects for increasing food production in the future, we will first explain theoretically the potential photosynthetic production of plants, starting from the quantity of the photosynthetically active portion of solar radiation that impinges on territories that can be under cultivation, and then we will examine the factors limiting the photosynthetic activity of plants and the possible ways to overcome and eliminate their influence. We will start from the fact that farming, as indicated above, will be carried out on an area of 5 billion hectares, of which (proportional to the total land area) 2.1 billion hectares can be in the tropical zone, about 0.5 billion hectares in the subtropical part of the Northern Hemisphere and 0.4 billion hectares in that of the Southern Hemisphere and, finally, 2 billion hectares in the temperate and near-polar zone of the Northern Hemisphere.

It is completely understandable that to calculate the theoretically possible photosynthetic productivity of plants, we should take the indexes of structurally full crops and plantations which can absorb much energy of solar radiation and utilize it with a high efficiency. Such can be crops and biocoenoses whose leaf area reaches $40-50,000 \text{ m}^2/\text{ha}$ at the period of maximum development. At this period such crops absorb up to 70-80% of the energy of the photosynthetically active portion of solar radiation falling on them, and an average of 50 or even 60% during the entire growing season.*

*See: A.A. Nichiporovich and S.N. Lhmora, Radiation Regimes of Agricultural Crops and the Problems of Their Water Supply and Drought-Resistance. Collection: "Physiology of Plant Resistance", Moscow, Izdatel'stvo AN SSSR, 1960; A.A. Nichiporovich, L.Ye. Stroganova, S.N. Lhmora, and M.P. Vlasova, Photosynthetic Activity of Crop Plants, Moscow, Izdatel'stvo AN SSSR, 1961.

Table 3

Zones	Possible Energy Transp/ areas of (40% of evap.dur. for all possible crop		Total amount of water areas, billion m ³
	total crops	active)	
	bill.	bill. kcal/	ing season
	hectares	ha	mm
Tropical	2,1	4,4	750 1130
Subtropical	1,0	2,8	475 665
Temperate	2,0	1,0	260 340
Total	5,1		38 500

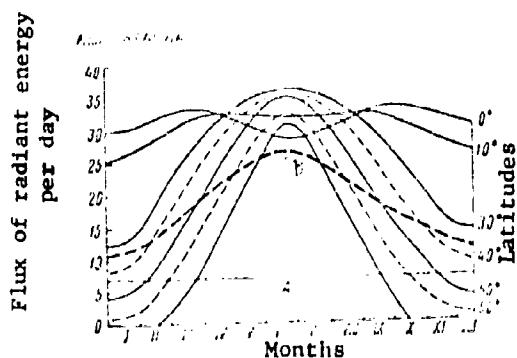


Fig. 3. Amount of photosynthetically active solar radiant energy falling per day per hectare of the earth's surface in various zones. A) line, below which radiation is inactive due to low intensity; B) line, below which radiation is inactive due to low temperature.

At best the plants can utilize absorbed radiant energy for photosynthesis with a consumption of 8 quanta, i.e., for solar light in an amount of 28% or, subtracting losses from respiration, about 20% of that absorbed.

In the final analysis, keeping in mind the possible 50% absorption of energy by full-value crops and the 20% utilization of its absorbed portion for photosynthesis, we can consider that crop plants utilize for photosynthesis and formation of yields, 10% of the photosynthetically active portion of the solar radiant energy that falls on them during the potential period of active growth.

These indexes enable us to calculate the theoretically possible photosynthetic efficiency and yield of plants in various geographical zones having different amounts of the radiant energy during the growing period.

These data are shown in Table 2, where the average amount of the impinging, physiologically active solar radiant energy ^{* (4)} given for the period when plants can grow in the various zones owing to temperature conditions (see also Fig. 3); the potential photosynthetic productivity of cultivated plants was calculated by starting from a 10% utilization of this energy during the entire period of possible growth, wherein it was assumed that the average heats of combustion of the biomass produced by the plants are equal to 4000 kcal/kg, or $4 \cdot 10$ kcal/ton.

This calculation gives us an idea of the possible, in principle, enormous seasonal yields of agricultural food and fodder plants both on a single hectare (biological yields of from 67 to 250 t/ha) and on all possible crop and plantation areas which exceed by several tens of times the present production of 11 billion tons from cultivated plants.

This is an ideal for which we can and must strive. However, the question justifiably arises as to what extent is the achievement of such indexes feasible. The fact is that they depend not only on the presence of various amounts of light energy, but also on many other concomitant factors: the thermal conditions, the water supply for the plants, mineral supplies, the concentration of carbon

^{*}See: N.Ya. Kondrat'yev, Radiant Energy of the Sun, Leningrad, Gidrometeoizdat, 1954.

dioxide, oxygen, etc.

Actually, the intensity and over-all resultant effects of the earth's carbon cycle, whose driving force is photosynthesis, are determined first of all by the quantities of solar radiant energy. This is the main factor causing and finally limiting the highest possible photosynthetic production of plants. However, the carbon cycle is most intimately associated with the cycles of nitrogen, mineral nutrition, and water and it is precisely these and the earth's thermal conditions that can be and indeed are the factors determining and limiting its intensity. For instance, we see from the data of Fig. 3 the limiting effect on the potential photosynthetic productivity of plants, of the thermal factor and the factor of the seasonal and latitudinal inequality of the distribution of solar radiant energy over the earth's surface.

A certain, although not especially appreciable portion of the sun's radiant energy cannot be considered as photosynthetically active, since its total daytime quantities prove to be less than that required for normal plant growth. In Fig. 3 this corresponds to the portions of the curves located below line A. In addition, a portion of the light energy actually proves to be inactive or slightly active because it reaches the earth at periods when the temperatures are too low for life activity and growth of the plants. This portion of the light energy is located below line B, and therefore only the energy corresponding to parts of the curves located above the line is actually active (these are the indexes that were taken for the calculations shown above, in Table 2). If this active energy, as we already said, were to be used for photosynthesis in accordance with the theoretical possibilities, then mankind would be able to produce a colossal production from the photosynthetic activity of plants. Our problem is to find the causes for the disagreement between the theoretical possibilities and the actual situation, and to find ways to eliminate these causes.

First of all it is necessary to note that, quite frequently our crops and plantations, because of poor farming techniques, shortages of nutrition and moisture, do not have the optimal structure which can ensure high coefficients of their absorption of solar radiant energy.

The data in Fig. 2 permit us to consider (and this is confirmed by a direct calculation) that on the average, crops whose leaf area at the maximum period reaches 40-50,000 m²/ha absorb 50% of the energy. But sometimes the leaf area in the crops is only 8-10-15,000 m²/ha. These crops absorb only 20-30% of the energy of solar radiation during the growing season, in other words, only 1/5 to 1/3 of the energy which crops with maximum structure can absorb. It is easy to imagine what enormous amounts of radiant energy we lose irretrievably: the energy not absorbed by the plants due to scantiness of the crops is converted to heat and dispersed into space. It is also easy to understand what vast reserves can be mobilized for increasing the photosynthetic productivity of plants if all crops will have an optimal structure, which is not at all unusual, but characteristic for many present crops.

No smaller are the avoidable losses arising because the biological characteristics of the growth and development of many of our plants, especially those developed under some conditions and then transplanted to others, do not correspond to the variations of meteorological factors and conditions of a given region. This can be illustrated by the example of the development of wheat and corn in the Moscow area in 1960 (see Fig. 4). Corn is sown here in June because of the thermal conditions. During the period of the longest days with the best light conditions (June to the first half of July), the plants (curve 1) only have two or three leaves each, and a negligible amount (5-10%) of the solar radiant energy falling on the crop area is absorbed while most of it passes into the soil. When the leaf area reaches the maximum, the light conditions deteriorate considerably (curve 2) and the photosynthetic efficiency of the corn drops abruptly (curve 4). At the same time, wheat (curve 3) utilizes the first part of the growing season, but ends growth before the light and thermal conditions become insufficient for active growth. Consequently, the potentially active light energy is very often used for photosynthesis extremely inefficiently, incompletely, and is made useless by the incompatibility of the rhythms of its variations and the life activity of the plants.

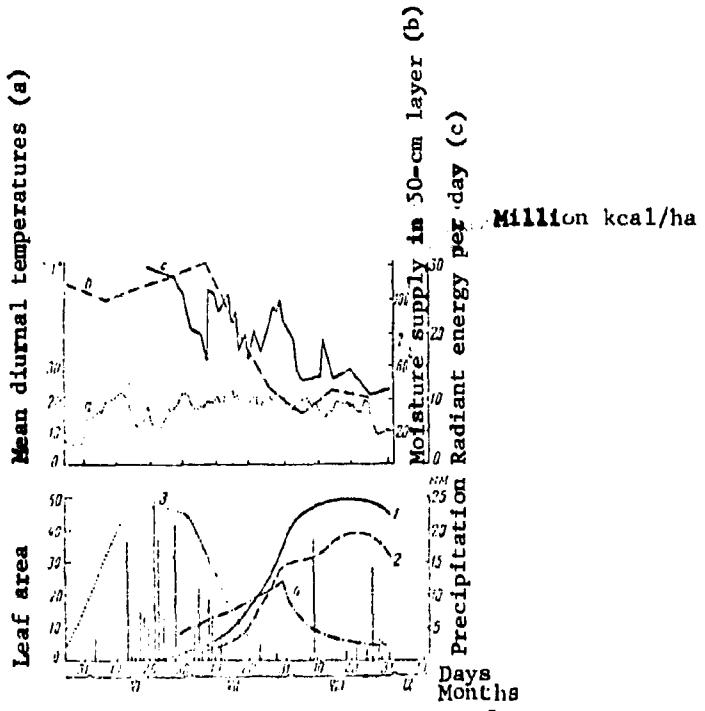


Fig. 4. Growth of leaf area ($1000 \text{ m}^2/\text{ha}$) in corn and wheat crops and the photosynthetic productivity under various conditions (g/m^2 per day).
 1) Corn with irrigation; 2) corn without irrigation;
 3) wheat; 4) photosynthetic productivity of corn with irrigation.

This can be eliminated to a considerable extent by a high specialization of agriculture and by the careful selection for various zones of species and varieties of plants whose biological rhythms best correspond to the changes of the light and thermal conditions.

Frequently, and to a severe extent, the potentially active light energy is made worthless by the inadequate and, in a number of cases, very harsh moisture condition; this is easily shown by the example of the desert belt (Sahara, Arabian and Central Asia deserts, Gobi) located between 20° and 40° N, where there are enormous streams of light energy, but practically no moisture.

Moisture is needed for the normal life activity of plants and to defray the transpiration losses which are organically related with photosynthesis in that they have the same energetic base: the parameters of both processes are determined by the amount of energy absorbed by the plants and crops and by its allotment for photosynthesis (usually 5-10%, in the best cases 20% of the absorbed energy) and for conversion to heat energy (the remaining 95-90% or in the best cases 80% of the absorbed energy).

In luxuriant crops which have no lack of water, the moisture supply should be such that all that is not used for photosynthesis or converted to heat energy is eliminated from leaves by transpiration. The potential transpiration in these cases is determined by dividing the indexes characterizing the amount of energy by the energy indexes of the latent heat of water evaporation. If these figures are increased by 30-50% in the appropriate zones (keeping in mind the unavoidable evaporation from the soil surface and run-off), then we can form an idea about the amounts of moisture which are needed in different geographic zones for the maximum use of the energy falling here for photosynthesis and for producing high yields. Such figures are shown in Table 3.

Evaluating the data of the Table, we must say that there are a number of territories and zones on the earth where the total precipitation is sufficient for producing the theoretically possible yields (the humid tropics, a number of zones in the temperate belt), but at the same time there are enormous territories

Table 2

ZONES	Potential crop area billion hectares	Total active		Potential annual plant productivity (total dry biomass) For entire area, billion tons	
		BILLION year	energy of solar radiation per kcal/ha area, kcal		
Tropical 23° S. - 23° N.	2,1	10,0	2,1 · 10 ¹⁸	250	525
Subtropical 23-43° N. 23-43° S.	0,6 } 0,4 }	7,0	0,4 · 10 ¹⁸ } 0,3 · 10 ¹⁸ }	175	105 70
Temperate & near trans- polar 43-70° N	0,2	2,5	0,5 · 10 ¹⁸	67	135
Total	5,1				835

which to a lesser or greater (and sometimes very severe) degree are not supplied with the needed amount of moisture. If here we do not use artificial irrigation, we can expect to obtain only low yields in comparison with the theoretically possible, and the solar radiation of these territories is to some extent, and sometimes completely (in deserts) wasted.

Every year about 500,000 billion m^3 of water is circulated (evaporated and falling as precipitation); this is about 12-13 times more than required (38,500 billion m^3) for optimal growth and photosynthesis of possible (in the future) crops of food and fodder plants (on an area of 5.1 billion hectares). The surface of the continents receive annually as precipitation $100 \cdot 10^{12} m^3$ of water, i.e., 2.5 times more than would be required to supply fully 5 billion hectares of crops. But approximately a third of this water ($36 \cdot 10^{12} m^3$) is not used by plants and runs off into the seas and oceans, and the remainder is distributed (very unevenly) on an area three times larger than the area of proposed future cultivation. Consequently, the areas now under and proposed to be under cultivation are provided with natural precipitation to a degree far less than is needed for maximum utilization of the energy of solar radiation for photosynthesis and production of high yields.

Therefore, one of the most important problems is to use the 38,000 billion m^3 of water out of the $100 \cdot 10^{12} m^3$ of water that annually falls on the continents to supply 5 billion hectares of future agricultural land; this can be done by various methods, e.g., better use of the precipitation, moisture storage in the fields, irrigation, etc. The solution of this problem begins, in essence, in our country now, in the epoch of developing the material and technological base of Communism. It suffices to recall that the new Program of the CPSR provides for extensive works on irrigation construction, these "daring plans for changing the course of certain northern rivers", which presently throw away fruitlessly enormous amounts of water into the Arctic Ocean; these plans, as indicated in the Program, can be accomplished by Soviet man during the course of communist construction.

It is necessary to search for ways other than those named which would foster a solution to the problem of providing water to enormous areas of future crops.

For example, the following method is possible in principle.

The water now in annual circulation is scattered (although extremely unevenly) in the vastness of the atmosphere, hydrosphere, and on the earth's surface and its effectiveness as a factor necessary for plant life is very reduced. It could be considerably higher if only a small portion of this water were separated from the large general circulation into an isolated volume of the atmosphere and soil and were to be circulated in its own particular cycle, first evaporating, then condensing, thus wetting the soil. In this case, with circulation of relatively small amounts of water, the same effect of the life activity and photosynthesis of plants could be ensured as that which we determined as the optimal possible effect. High plant yields could be grown on a water supply 10 times smaller than that which present open crops expend for evaporation, that is, on a constant supply of 500-600 m^3/ha , of which 30-50 m^3 would be evaporated annually, but then condensed, returned to the soil, and thus the required moisture regime would be maintained in the soil and root substrate.

It is necessary to say that with the usual farming methods we always strive to separate a number of factors from the over-all large circulation of substances and to create particular, local circulations. This refers, for example, to nitrogen, to the elements of mineral nutrition. One of the difficulties of supplying nitrogen and ash elements to plants in crops and plantations is that these elements are rapidly scattered in the vastness of the external environment by, first, crop absorption and, second, by erosion and washing and, in the end, carry-off to the seas and oceans. In order to overcome this we must first of all use mineral fertilizers. However, the greatest effect is achieved if we simultaneously take measures which reduce to a minimum erosion and scattering of the elements. In other words, we must separate the particular, local circulations from the over-all large circulation of substances as much as possible. Such measures are accom-

plished and used rather widely: this is a return to the fields of plant nutrients in the form of manure, feces, ashes, in the form of the dry residue of sewage; this is the totality of measures taken to combat soil erosion; this is the return of nitrogen to the soil and plants by fixation of atmospheric nitrogen by nitrogen-fixing organisms and leguminous plants, by green algae.

A maximum return to the soil of river waters flowing into the oceans could help solve the problem. These waters, carrying with them vast amounts of nutritive substances, aggravate conditions of plant photosynthesis on land where its production can be used for food with the greatest efficiency, and improve conditions for photosynthesis in seas and oceans, where photosynthetic production is nonetheless great, but the coefficients of its possible utilization for food purposes extremely low.

A low partial pressure of carbon dioxide in the atmosphere and a high partial pressure of oxygen are an important factor limiting the rate and extent of the photosynthetic activity of plants. This factor in its present state came into existence on the earth during the course of historical development. As green plants appeared and became widely distributed, the earth's atmosphere as a result of their photosynthesis became rich in oxygen and poor in carbon dioxide. At the present time on earth, as much carbon dioxide is formed daily ^a as a result of biologic and abiotic oxidation of organic materials as is assimilated by plants during photosynthesis. However, the carbon dioxide formed during oxidation of the organic materials is dispersed into the atmosphere and hydrosphere, and its concentration proves to be very low. This is an unfavorable factor for photosynthesis, which is easily proved by the good responsiveness of photosynthesis to an increase in the carbon dioxide concentration in the air around the plants.

In agricultural practice and in this case, there are methods to separate a portion of the carbon from the over-all, large circulation, to prevent its excessive dispersion, and to keep it in local cycles. This is achieved by returning organic substances to the fields as manure, feces, and composts, or by using

carbon dioxide fertilizers in closed or even open ground.

It is true that a suitable water and mineral supply to plants produces very good and high yields at the present level of atmospheric carbon dioxide. However, if it were possible to prevent its dispersion into the vastness of the atmosphere and hydrosphere and to concentrate it in the ground air layers and on the surface layers of water, having increased its concentration by several times (although only to 0.1%), then it would be possible to increase greatly the photosynthetic productivity of plants, to intensify carbon circulation, and as a result, to draw into the biological circulation additional supplies of carbon from carbonates, and thus increase the volume of life on our planet. This is difficult and virtually impossible on an earth-wide scale, but it can be accomplished on limited areas.

In the simplest form (return of carbon to the soil as organic fertilizers containing mineral nutrients, the use of sewage water for irrigation, prevention of run-off, water storage, etc.) such circulations are widely used and should be used in modern agriculture as the most important method to increase yields. But in the present form they are only a partial solution of the problem, only half-measures, in spite of exceptional moisture, wide accessibility, and distribution.

From the fundamental point of view, the most radical solution of the problem would be to create absolutely or maximally closed systems with complete or almost complete internal circulation of substances.

The main characteristics of such systems would be a transparent cover having maximum heat conductivity and the cultivation of plants in a soilless culture (hydroponics), which would eliminate the need to return the organic material to the soil and which would make possible a more complete utilization of the primary biomass of the plants for fodder and food purposes.

It is advantageous to have as the components of closed systems, the most valuable and productive agricultural plants and also a massive cultivation of unicellular algae (e.g., Chlorella), which has a number of important features:

during the entire period when there is sufficient light, the temperature of the suspension can be maintained at the optimal level; the daily liberation of the growing biomass makes it possible to maintain at all times the density of the suspension at a level favorable, on one hand, for the complete absorption of light and good photosynthesis and, on the other hand, for a sufficiently vigorous division and multiplication of the cells. Owing to this, the algal culture can be more productive than the cultivation of higher soil plants with their rather long period for the appearance and growth of shoots, for development, while they have a small total leaf area and absorb only a small part of the solar radiant energy impinging on the crop, while the rest passes into the soil. In addition, Chlorella by liberating much oxygen into the liquid medium as a result of photosynthesis, strongly stimulates oxidation of organic sewage materials and can promote oxidation of human and animal wastes, forming in place of these wastes their own biomass and boosting the formation of the bacterial biomass which is suitable for animal feed, and thus drawing human and animal wastes into the closed carbon cycle. The carbon dioxide being formed as a result of bacterial activity could be used for photosynthesis of higher plants and Chlorella. The protein-rich (up to 50% per dry weight) algal biomass can serve as food for invertebrate animals, for example, crabs, infusoria, whose biomass in turn can be a good feed for domestic birds (ducks, chickens), and also for fish. Therefore, the combination of higher plants and an alga in closed systems is expeditious from many points of view.

Under conditions of closed systems, with a suitable selection of plants capable of producing the highest yields of useful food or fodder biomass after it is efficiently processed, the coefficients of food utilization of the photosynthetic production can be increased to very high values, probably to 40%. In this case it is necessary to produce about 1000 kg of primary biomass in order to supply a person with 1 kg of food per day, or 365 kg per year.

In the above-described closed system, we can expect to obtain yields of total dry biomass of plants of 50-60-100 t/ha and even 100-150 t/ha in southern regions

with an active growing season of 250-300 days. In this case, food for man can be provided by the photosynthetic production of plants cultivated on 200-150 and even 100-50 m².

We can point out that with the present type and level of agriculture, food for one person is supplied, on the average, by the cultivation of food and fodder plants on an area of one hectare, and in good cases, on 0.5 ha. Closed systems can supply a person with food by cultivating the plants on an area about 40-50, and even 100 times smaller.

These systems can be of various types, can include different combinations of organisms, and have a different degree of being closed. It is natural that the problems of the expeditiousness of their use under different conditions must be solved differently. Probably, they will be least effective in zones with a hot, humid climate, where high yields can be obtained without them with a suitable farming practice. The use of closed systems in desert zones having abundant light but a dearth of water is the most suitable. Their value in northern latitudes goes without saying, especially close to industrial enterprises having an abundance of waste gasses. In these cases, not only would carbon dioxide, water-supply, and mineral nutrient conditions be created that are suitable for plants, but also the limiting effect of low temperatures, which is severe under high-latitude conditions, would be eliminated.

Of course the wide application of closed systems is a matter not of the near future. At first they seem to be too complex and expensive. However, it is necessary to remember the colossal wastefulness of present-day agriculture which abets dispersion of very valuable nutrient elements, water, carbon and the enormous waste of solar radiant energy. Closed systems can almost completely eliminate these losses. It is also necessary to take into account that under certain conditions (for example, the development of efficient sources of artificial light, of perfected transparent plastics), they will be used widely not only in territories of light-rich deserts and semideserts, but also in extensive areas of the seas and oceans, in subterranean structures, which will facilitate air-

tightness and maintenance of the required thermal conditions.

Closed systems--this is the obvious and inevitable, practically limitless way which in the future should occupy a solid position in the complex of measures to be taken for the best and most efficient utilization of the photosynthetic function of plants for the production of food.

If in the regions with a sufficient amount of heat and moisture, the areas and light are used to the maximum for the cultivation of the most valuable food and fodder plants during the entire or most of the year,

if in the selection of the varieties and types of plants for different regions, the highest degree of specialization is reached and they can maximally absorb light energy during the entire growing season or even during the year, with its highest efficiency for photosynthesis,

if the principle of the creation and maintenance of local cycles of nutrient elements, nitrogen, carbon, and, especially, water will be used widely and completely in conformity with the amounts of impinging solar radiant energy and with the photosynthetic potentialities of the plants,

if, finally, completely closed cultivation systems for plants, algae, and the heterotrophic organisms accompanying them are widely used in the future,

then we can expect an increase in the photosynthetic production of food and fodder plants, a solution to the problem of food resources such that unlimited possibilities for ensuring the future progress of mankind will be created.

Of course the realization of these potentialities requires great efforts. But man presently has at his disposal such knowledge which, if it is not criminally used for military purposes, will open vast prospects for influencing the most important processes of nature.

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